Comparative Study of Mutual Coupling on Microstrip Antennas for Wireless Local Area Network (WLAN) Application

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***Abstract*- The increasing in interest of wearable antenna for military, sport, and medical applications may replace the uses of wired-communication network to wireless and wearable network. . In this paper, three shapes of the antennas which resonate at 2.4GHz and 5.2 GHz have been designed using jeans with the permittivity constant of 1.7 as the dielectric. The mutual coupling of the array antenna for the various shapes has been analyzed in H-plane and E-plane configuration respectively. The mutual coupling for the antenna in E-plane configuration has shown more sensitive toward the variation of distance between the elements, with compared to the elements in H-plane arrangement.**

***Index Terms*- Dual-band, Wearable Antenna, Array Antenna, Mutual Coupling.**

I. INTRODUCTION

Recently, wearable antennas are becoming more attractive for on-body and off-body communication systems [1-4]. Wearable antennas have been designed using flexible substrate or fabric materials such as jeans, felt and etc. with flexibility properties. These types of substrate can be easily attached to the clothes and can be worn [2]. There are various Wireless Local Area Network (WLAN) applications for wearable antenna consequently applicable for network communications at 2.45 GHz and 5 to 6 GHz which especially applicable for military, medical, health care, emergency services and navigations [5].

This paper presents the design of wearable fabric antenna which covers the operating frequencies of 2.4GHz and 5.2GHz. Microstrip antennas which are low cost, low profile, and easy to manufacture are attractive for the wireless communication [6, 7]. Three shapes of microstrip patch antenna which are circle, rectangular and square have been designed for this purpose. The characteristics of the arrays antennas especially their mutual coupling have been discussed and compared through this paper.

A. Wearable Antenna Specifications

Increasing demand of wearable antenna has attracted researchers to explore new antenna design which using textile dielectric. As common requirement for antenna design, wearable antenna is need to be low profile, light weight, easy to manufacture and zero maintenance [8].

In this paper, the textile antennas operate at 2.4GHz and 5.2GHz which using fabric jeans as the substrate has been developed. Copper sheet which has been cut to the respective antennas and ground shapes has been stick onto the fabric and act as the conducting elements. The design can be tailored or stitched onto the fabric and the structure does not limit the placement of the design on the fabric. The typical design steps for wearable antenna is shown in Figure 1 [8].

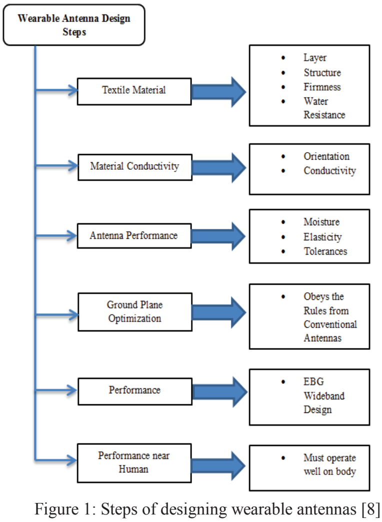


Figure 1: Steps of designing wearable antennas [8]

To design a good wearable antenna design, the material selection must be suitable for the application. The basic design of a wearable antenna should follow the rules of designing conventional antennas. Manmade structures such as Electromagnetic Band gap (EBG) might be needed to improve the performance of the wearable antenna such as for radiation pattern and diversity application [9, 10]. To ensure the suitable of the antenna for on-body application, further analysis can be conducted to test the antenna on human body. This might be very useful to make sure that the antenna operates well on body [11].

B. Antenna Arrays

A good antenna performance does not only determine from the antenna's return loss characteristic, but also on their gain and radiation pattern [10]. Normally, it is not sufficient for a single element of antenna to achieve the high gain of the radiation pattern. Hence, the problem can be improved by combining a number of antenna elements and arranging them in array. There are two basic dimensions for the array arrangement, either in 1-D or 2-D configurations. 1-D antenna array always been focused as the arrangement is easier and simpler to be designed and fabricated.

Radiation pattern of an antenna changes when there are several antenna elements are combined in an array. The overall radiation pattern varies with the change of directivity and gain of the antenna array. There are certain aspects affecting the performance of the antenna array including the number of elements on the array factor and also the space between each element [11]. The larger the numbers of array element and the element spacing, the higher the directivity of the antenna array. Hence, improves the overall efficiency of the structure.

C. Mutual Coupling of Array Antenna

Mutual coupling for the array antenna has been analyzed in this paper since it affects the current distribution, phase, input impedance and radiation pattern of each antenna element [12]. Generally, in order to achieve the low correlation with high isolation between the elements, the antenna elements must be spaced by more than λ/4 , where λ is the free space wavelength at the specified frequency [13].

A number of studies on reducing the mutual coupling between closely-spaced microstrip antennas especially for PIFAs have been conducted. For the design of an array of infinite elements, minimal mutual coupling is the fundamental limit to be focused on as published in [14]. Therefore, in this paper, the effect of varying the distance between the arrays elements which contribute towards the performance of the antenna has been simulated and analyzed.

D. Simulation Technique of Array Antenna

The simulations of the antenna and array S-parameters have been conducted and focused on 2.4GHz and 5.2GHz band respectively. The array has been arranged in H-plane or E-plane configuration.

The ground plane of H-plane orientation is connected for both arrays while the ground plane of the E-plane is separated. The complex S_{12} parameter has been measured as the element spacing of each configuration has been made varied.

In order to provide continuous substrate, dielectric spacers has been inserted between the two elements as the element spacing increased [14].

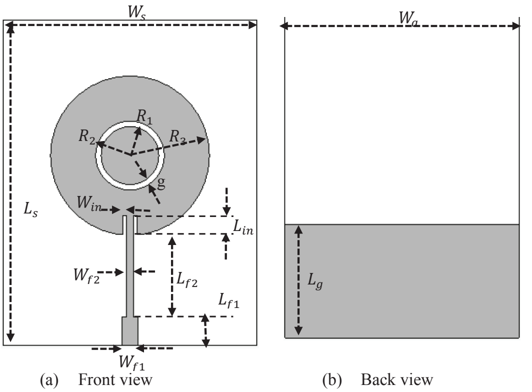
II. ANTENNA DESIGNS

The study has been done by selecting three patch antenna designs; circular, rectangular and square shapes. Although there a lot designs which designed by various researchers, these types of antenna are the common types for millimetre wave frequencies which commonly studied. In this analysis, the antenna has been designed and matched with microstrip feed connection in order to delivered maximum power transmission.

A. Circular Patch Antenna Design Parameter

The proposed antenna has chosen based on a design of textile antenna for wearable body area application [2]. The antenna is fabricated on a 70x90mm jeans substrate textile material with relative dielectric constant of 1.7 and thickness of 1.2mm.

The geometry of the proposed design is illustrated in Figure 2. It consists of a circular disc with a radius of 22mm and a smaller circular slot which contribute toward the lower and higher band respectively.

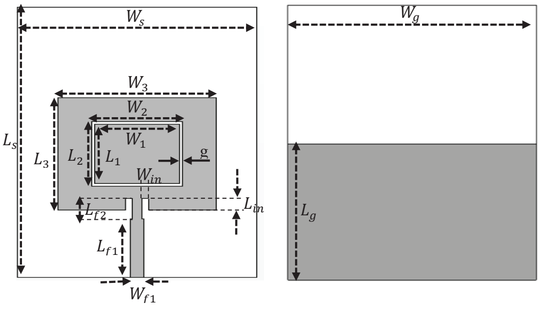


(a) Front view (b) Back view

Figure 2: Geometry and configuration of the proposed circular patch design

B. Rectangular Patch Antenna Design Parameter

The geometry of the proposed design is illustrated in Figure 3. The material of the antenna used is the same as the circular patch which is jeans substrate and copper tape as the conducting material.



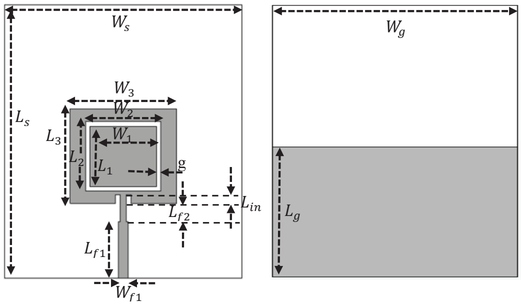
(a) Front view (b) Back view

Figure 3: Geometry and configuration of the proposed rectangular design

C. Square Patch Antenna Design Parameter

The antenna design consists of a square patch with a slot inside the structure to perform dual-band properties. Figure 4 shows the geometry of the proposed design.

Tables 1, 2 and 3 list the dimensions of the proposed antennas. The calculated values are parameters that have been identified using equations that have been discussed in [8,11]. With some parameter sweep for simulation, the optimized values for the proposed design have been achieved as shown in the tables.



(a) Front view (b) Back view

Figure 4: Geometry and configuration of the proposed square design

Table 1
Dimension of Proposed Circular Patch Antenna

Parameters	Dimensions (mm) Calculated	Optimized
Dielectric constant or relative permittivity (ε_r)	1.7	1.7
Width of Substrate (W_s)	121.83	70
Width of Ground (W_g)	77.8	70
Width of Microstrip Feed I (W_{f1})	4.3	4.3
Width of Microstrip Feed II (W_{f2})	-	2
Width of Inset Feed (W_{in})	-	1
Length of Substrate (L_s)	121.63	90
Length of Ground (L_g)	77.8	30
Length of Microstrip Feed I (L_{f1})	-	8
Length of Microstrip Feed II (L_{f2})	-	23
Length of Inset Feed (L_{in})	-	5
Radius of Slotted Circular	Inner (R_1) = 13 Outer (R_2) = -	Inner (R_1) = 8 Outer (R_2) = 9.5
Radius of Circular Disc	R_3 = 28.1	R_3 = 22
Gap between slot (g)	-	1.5
Thickness of Substrate (h)	1.2	1.2
Thickness of Patch	0.02	0.02
Thickness of Partial Ground Plane	0.02	0.02

Table 2
Dimension of Proposed Rectangular Patch Antenna

Parameters	Dimensions (mm) Calculated	Optimized
Dielectric constant or relative permittivity (ε_r)	1.7	1.7
Width of Substrate (W_s)	121.63	109
Width of Ground (W_g)	77.8	109
Width of Microstrip Feed I (W_{f1})	4.3	4.3
Width of Microstrip Feed II (W_{f2})	-	3
Width of Inset Feed (W_{in})	-	2
Width of Slotted Rectangular	Inner (W_1) = 24.8 Outer (W_2) = -	Inner (W_1) = 30.5 Outer (W_2) = 34.5
Width of Rectangular	W_3 = 53.8	W_3 = 49
Gap between slot (g)	-	2
Length of Substrate (L_s)	121.63	121.3
Length of Ground (L_g)	77.8	60
Length of Microstrip Feed I (L_{f1})	25	25
Length of Microstrip Feed II (L_{f2})	3.6	8
Length of Inset Feed (L_{in})	-	4
Length of Slotted Rectangular	Inner (L_1) = 21.1 Outer (L_2) = -	Inner (L_1) = 26.8 Outer (L_2) = 30.8
Length of Rectangular	L_3 = 47.1	L_3 = 42
Thickness of Substrate (h)	1.2	1.2
Thickness of Patch	0.02	0.02
Thickness of Partial Ground Plane	0.02	0.02

Table 3
Dimension of Proposed Square Patch Antenna

Parameters	Dimensions (mm) Calculated	Optimized
Dielectric constant or relative permittivity (ε_r)	1.7	1.7
Width of Substrate (W_s)	121.63	75
Width of Ground (W_g)	77.8	75
Width of Microstrip Feed I (W_{f1})	4.3	4.3
Width of Microstrip Feed II (W_{f2})	-	3
Width of Inset Feed (W_{in})	-	2
Width of Slotted Rectangular	Inner (W_1) = 24.8 Outer (W_2) = -	Inner (W_1) = 26.4 Outer (W_2) = 28.4
Width of Rectangular	W_3 = 53.8	W_1 = 49.7
Gap between slot (g)	-	1
Length of Substrate (L_s)	121.63	120
Length of Ground (L_g)	77.8	62.5
Length of Microstrip Feed I (L_{f1})	25	26
Length of Microstrip Feed II (L_{f2})	3.6	4
Length of Inset Feed (L_{in})	-	5
Length of Slotted Rectangular	Inner (L_1) = 24.8 Outer (L_2) = -	Inner (L_1) = 26.4 Outer (L_2) = 28.4
Length of Rectangular	L_3 = 53.8	L_3 = 49.7
Thickness of Substrate (h)	1.2	1.2
Thickness of Patch	0.02	0.02
Thickness of Partial Ground Plane	0.02	0.02

D. *Simulation Results of Patch Antenna*

The operating frequency of this design is 2.4 GHz and 5.2 GHZ with return loss less than -10 dB and bandwidth more than 200 MHz in order to deliver best antenna performance; Table 4-6 show the simulated results the three types of antenna patch designs. The return loss, directivity, realized gain and radiation efficiency of these antennas have been identified in order to study the performance of each antenna.

Table 7 shows the return loss of three antenna types which are circular, rectangular, and square patch. The best return loss is obtained from the simulation of circular patch antenna with compared to the other two types of antenna; rectangular and square patch. From these results, it can be concluded that every type of antenna meets the requirements of antenna performances.

Table 4
Simulation Results of Circular Patch Antenna

Type of Patch	Circular	
Frequency (GHz)	2.4	5.2
Return Loss (dB)	-16.374	-36.362
Directivity (dBi)	3.597	3.405
Realized Gain (dB)	3.488	3.376
Radiation Efficiency (dB)	-0.0073	-0.0282

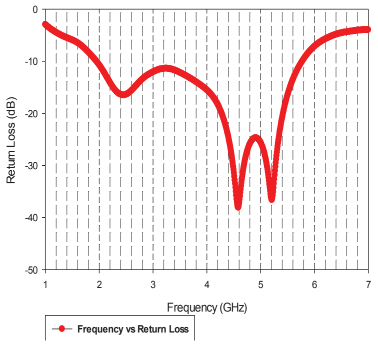
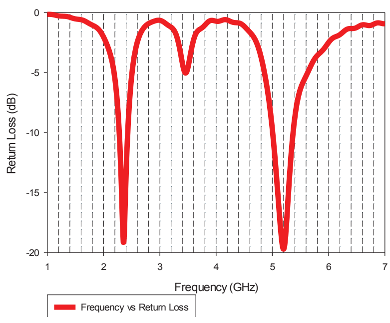
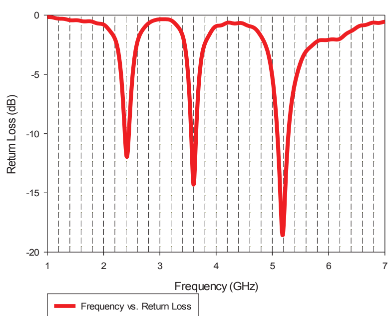
Table 5
Simulation Results of Rectangular Patch Antenna

Type of Patch	Rectangular	
Frequency (GHz)	2.4	5.2
Return Loss (dB)	-11.620	-17.819
Directivity (dBi)	6.205	6.250
Realized Gain (dB)	5.725	6.097
Radiation Efficiency (dB)	-0.1695	-0.0803

Table 6
Simulation Results of Square Patch Antenna

Type of Patch	Square	
Frequency (GHz)	2.4	5.2
Return Loss (dB)	-13.435	-19.716
Directivity (dBi)	4.923	5.289
Realized Gain (dB)	4.616	5.147
Radiation Efficiency (dB)	-0.1058	-0.0962

Table 7
Return Loss of Patch Antennas

Type of Patch	Return Loss
Circular	
Rectangular	
Square	

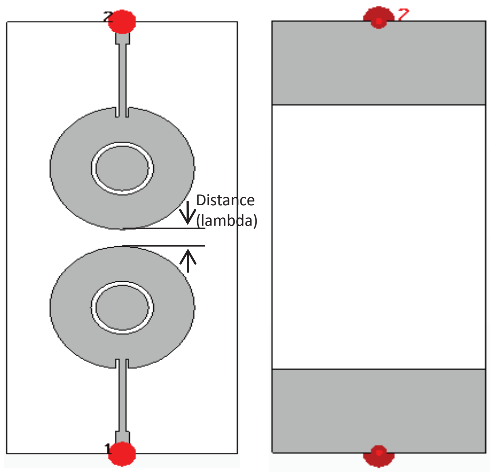
III. Array Antenna

A. Array Antenna Design

The array antenna is designed in order to study the mutual coupling characteristic of the antenna. The effect of mutual coupling can be analysed by varying the distance between both antennas. The separation between elements is varied from 0.2 λ up to 2 λ

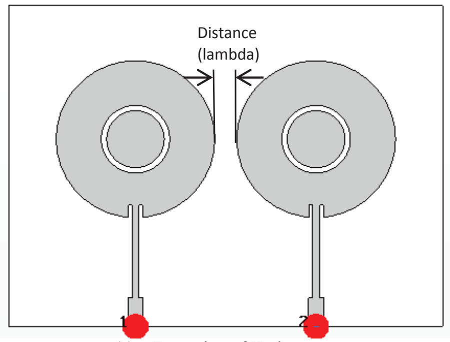
The proposed array antenna is designed based on the single antenna which operates at dual-frequency, 2.4 GHz and 5.2 GHz. The E-plane and H-plane arrangement for circular patch array antenna design is shown in Figure 8 and Figure 9 respectively. The arrangement of rectangular antenna in E- and H-plane arrangement is shown in Figure 10 and Figure 11 respectively. Whereas, Figure 12 and 13 represent the arrangement in E- and H-plane for square patch antenna array.

When the elements are placed collinearly along the E-plane, this arrangement is referred as the E-plane, as shown in Figure 8, 10, and 12. On the other hand, when the elements are positioned collinearly along the H-plane, the arrangement is referred to as H-plane, as shown in Figure 9, 11, and 13.

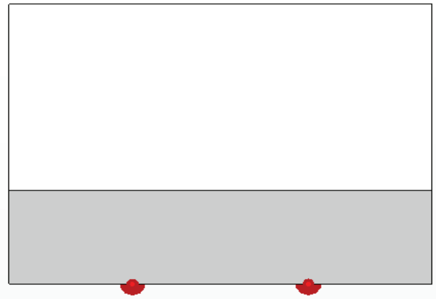


(a) Front view of E-plane geometry (b) Back view of E-plane geometry

Figure 8: Geometry of the circular array antenna in E-plane

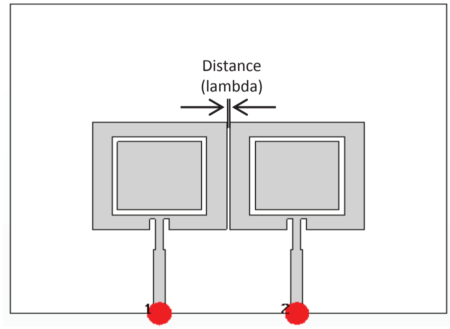


(a) Front view of H-plane geometry

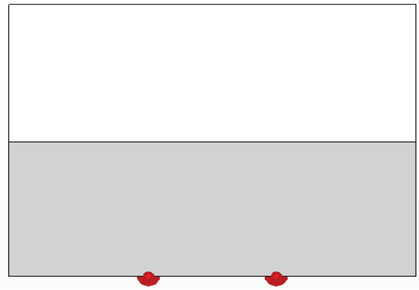


(b) Back view of H-plane geometry

Figure 9: Geometry of the circular array antenna for H-plane

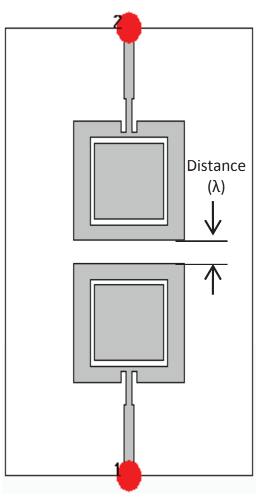


(a) Front view of H-plane geometry

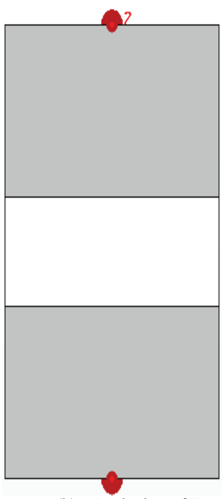


(b) Back view of H-plane geometry

Figure 11: Geometry of the rectangular array antenna for H-plane

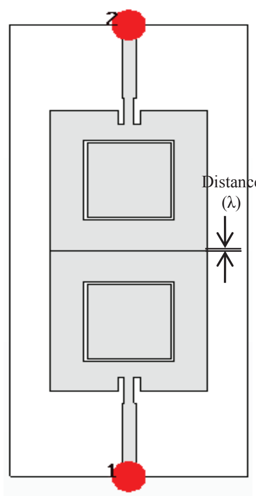


(a) Front view of E-plane geometry

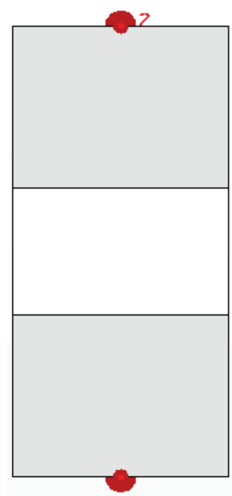


(b) Back view of E-plane geometry

Figure 10: Geometry of the rectangular array antenna in E-plane

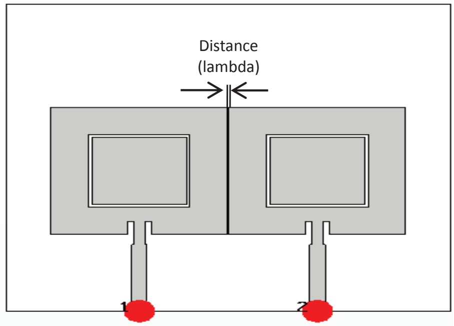


(a) Front view of E-plane geometry

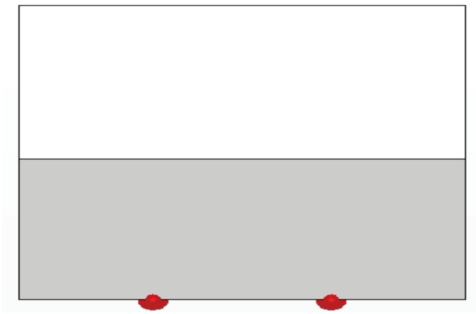


(b) Back view of E-plane geometry

Figure 12: Geometry of the square array antenna in E-plane



(a) Front view of H-plane geometry



(b) Back view of H-plane geometry

Figure 13: Geometry of the square array antenna for H-plane

B. *Simulation Results of Array Antenna*

From the patch antenna that has been designed earlier, the effect of array antenna on the mutual coupling has been studied.

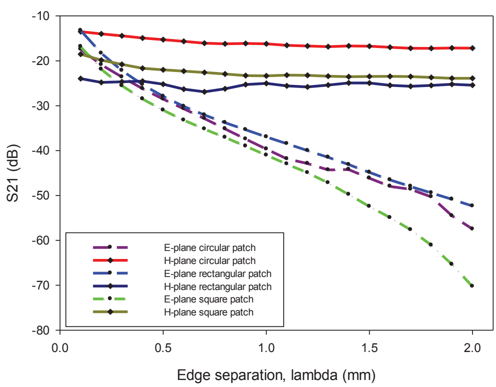


Figure 14: Mutual coupling for antenna transmission at 2.4 GHz

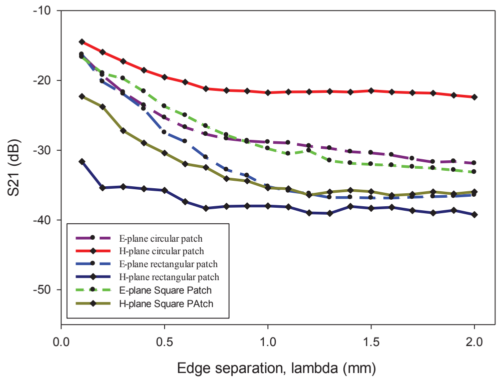


Figure 15: Mutual coupling for antenna transmission at 5.2 GHz

Characterization results for proposed antennas in term of mutual coupling of the antennas are plotted in Figure 14 and Figure 15. Mutual coupling between array elements is a potential cause affecting performance degradation. Therefore, for an antenna array design, it is important to determine mutual coupling using numerical analysis.

The mutual coupling of the array antenna in this paper is characterized by referring to the S_{12} of the antenna. In the design of an antenna, the values of the output are as below:

$$S_{12} = S_{21} \text{ and } S_{11} = S_{22} \quad (1)$$

The S_{12} value presents the power transferred from Port 2 to Port 1 while S_{21} is the power transferred from Port 1 to Port 2. Besides that, the S_{11} and S_{22} are the reflection coefficient of the antenna. The definition of reflection coefficient which is also called as return loss is defined as the amount of power reflected from the antenna. S_{11} (dB) must be lower than -10dB to get acceptable performance.

The mutual coupling between the array for both E-plane and H-plane for all types of antennas are shown in Figure 14 and Figure 15. In Figure 14, it shows the effect of mutual coupling towards the transmission of antenna at 2.4 GHz while Figure 15 is the effect of mutual coupling at 5.2 GHz. Generally, mutual coupling of the array antenna is due to both space and surface wave which is shown through the placement of E-plane and H-plane array.

Suppression of the coupling current on the ground is important in order to achieve good isolation between the arrays of antenna especially for far-field coupling. For closely spaced antennas, near-field coupling is predominant as it includes two primary aspects such as the ground plane and the displacement current.

Referring to the array mutual coupling result as in Figure 14 and Figure 15; the transmission of the antenna increases linearly for H-plane for both frequencies as the distance between the array antenna increases. For edge-to-edge separation, the H-plane exhibits the smallest coupling isolation for very small spacing.

The mutual coupling of the antenna patches decays monotonically and rapidly as the spacing increases for E-plane configuration. The increased values of E-plane are due to the E-plane radiation between the elements. There are low current disturbance between the elements when the elements are placed at E-plane arrangement.

By comparing the results of E-plane and H-plane at both frequencies, the mutual coupling of E-plane is more stable if compared to H-plane. This is clearly shown at the frequency of 2.4 GHz as established in Figure 14. The E-plane arrangement is more stable with compared to H-plane distribution is due to current flowing on the ground plane does not cause interruption of the radiation for each elements especially for circular patch.

The displacement current between antenna elements and the ground plane connection in H-plane does contribute to the coupling of the array which caused the unstable mutual coupling for H-plane. When there is connection to ground plane for each element, the current tend to flow from one antenna to another and this will affect the mutual coupling of the H-plane configuration.

In order to identify the characteristics of mutual coupling for each antenna configuration, the E- and H-plane of the array have to be analyzed. At 2.4 GHz, the E- and H-plane of circular patch does not show any crossover. For rectangular patch, there is crossover between E- and H-plane at approximately 0.7GHz while for square patch antenna; the crossover exists at approximately 0.5GHz.

There is about 3dB isolation enhancement in both E- and H-plane couplings for the rectangular antenna with compared to square patch antenna. This observation shows that the rectangular patch have a better isolation with compared to the square patch. These characteristics are different for 5.2 GHz. There are no crossover occur for the three types of patch antennas. However, the circular and square patch shows a more stable result as either in E- or H-plane arrangements. Rectangular patch shows an unstable result due to the current flowing in E- and H-field has been disturbed by the different dimension of width and length for the antenna.

From the results of mutual coupling and the performances of the antenna, circular patch shows the most stable configuration compared to the other two antennas.

IV. CONCLUSION

Mutual coupling is one of the most important factors need to be considers for array antenna for various applications. For the design of antenna array, it is crucial to study its behaviour based on the mutual coupling effect for both E-plane and H-plane configurations. In this paper, the mutual coupling between the elements for both planes has been studied where the spacing within element edges has been varied from 0.1λ to 2.0λ.

Simulated mutual coupling results show that the rectangular patch have a good isolation enhancement especially at the frequency of 2.4 GHz while circular patch having the most stable result at 2.4 GHz and 5.2 GHz. The edge separation between antenna in both E-plane and H-plane configurations affect the performance of the antenna especially in their return loss and the mutual coupling. There is no severe effect when varying the distance separation between the circular elements with compared to the rectangular and square patch arrays.

Therefore, in studying array antenna, the performance of the array on mutual coupling should not be neglected. In this paper, it is shown that the type of antenna design does not give much effect on the mutual coupling between the elements.

Antenna with wearable dielectric of jeans used in this design make the antennas are suitable for wearable application. . However, all the design has shown almost similar performance in mutual coupling.

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